U.S. Department of Energy, Grand Junction, Colorado

Calculation Cover Sheet

Calc. No. <u>X0064900</u> **Discipline:** <u>Engineering</u> **Number of Sheets:** <u>6</u>

Project:
Moab Ground Water

Site:
Moab, Utah

Feature:
Land Applied Evaporation System, Allowable Application Rates

Sources of Data:

Steffen, Robertson and Kirsten, 2000. *Dewatering Options for placement of Cover Moab Tailings Impoundment,* prepared for Moab Mill Reclamation Trust, c/o PricewaterhouseCoopers LLP, SRK Project Number 128702, June

Sources of Formulae and References:

Lambe, T.W. and R.V. Whitman, 1969. *Soil Mechanics,* John Wiley and Sons, New York, N.Y.

Li, R-M, Stevens, M.A. and D.B. Simons, 1976. "Solutions to Green-Ampt infiltration equation," *Journal of the Irrigation and Drainage Division,* American Society of Civil Engineers, 102(IR2):239-248.

Linsley. R.K. Jr., Kohler, M.A., and J.L.H. Paulhus 1975. *Hydrology for Engineers,* second edition, McGraw-Hill, New York, N.Y.

Rawls, W.J. and D.L. Brakensiek, 1989. "Estimation of soil water retention and hydraulic properties," *in Unsaturated Flow in Hydrologic Modeling Theory and Practice,* edited by H.J. Morel-Seytoux, Kluwer Academic Publishers, pp. 275-300.

Snyder, R.L., Bali, K., Ventura, F., and H. Gomez-MacPherson, 2000. "Estimating evaporation from bare or nearly bare soil," *Journal of Irrigation and Drainage Engineering,* American Society of Civil Engineers, 126(6):399-403.

Preliminary Calc. ☐ **Final Calc.** ☒ **Supersedes Calc. No.** _____

Rev. No.	Revision	Calculation by	Date	Checked by	Date	Approved by	Date
		A Smith	2-23-04	K. Lupp	2-23-04	T Wright	2/23/04

Problem Statement

Determine the quantity of water that can be applied to the surface of the tailings that will be evaporated and not percolate into the tailings. Saturation of surface soils or runoff of water is not allowed.

Method of Solution

1. Review literature to determine an approximate infiltration depth that moisture will be removed through solar evaporation, i.e. without the addition of plant transpiration and soil physics controlling moisture infiltration into soil.
2. Determine the daily site potential evaporation (PE) rate using hourly data from the site weather station for July 2002 through June 2003.
3. Compute average monthly PE from the daily values of PE.
4. Estimate soil hydraulic properties for tailings at the impoundment surface.
5. Define a variable for the time to allow Stage 1 evaporation to occur, (Te). This is defined as the daily time period evaporation that is greater than the average daily evaporation.
6. Compute total daily evaporation (TDE) as:

$$TDE = Te * PE$$

7. Equate TDE to the allowable depth of infiltration (I).
8. Equate the allowable application rate (r) to the daily site evaporation rate (PE).
9. Compute the allowable depth of infiltration (I) with one-dimension Green-Ampt theory (see reference 1):

$$I = t * r$$

10. Determine moisture application rates with respect to time honoring the depth of infiltration.

Assumptions

1. Estimated soil properties adequately represent field conditions.
2. One-dimensional Green-Ampt infiltration theory holds.
3. Daily site evaporation rates for July 2002 through June 2003 can be used to predict future annual site evaporation rates.

Computer Source

Excel 2000

Calculation

1. Evaporation of water from a soil surface can be modeled as a two-stage process (Snyder et al. 2000) During Stage 1, the evaporation rate is determined by the amount of energy available to vaporize water at the soil surface. During the Stage 2, the evaporation rate is determined by soil hydraulic factors that specify transfer of moisture to the surface, e.g. soil capillarity. For this application, water should be applied at a rate for only the Stage 1 evaporation to remove all applied moisture. According to Green-Ampt infiltration theory, moisture will not pond on the soil surface as long as the rainfall rate, or application rate is less than the saturated hydraulic conductivity (*Ksat*) of the soil (Li et al. 1976).

2. Potential daily evaporation rate is computed with an energy-budget equation proposed by Penman (Linsley et al. 1975) later modified by Monteith by introducing the concept of resistances to make the wind function explicit. Potential evaporation is computed hourly with the Penman-Monteith equation using measured climatic values for solar radiation, air temperature, relative humidity, and wind speed. A weather station operated by the DOE exists at the Moab Project site directly north of the administration trailers that measures these and other climatic values. The weather station in automated with a Campbell-Scientific CR-10X datalogger that is programmed to compute potential evaporation rate (PE) with the Penman-Monteith equation on an hourly basis. Measured climatic values and computed PE rates are kept at the DOE's Office in Grand Junction, CO and this information is not reproduced herein. Hourly PE rates computed from July 2002 through June 2003 will be used to evaluate the evaporation from the tailings impoundment.

3. Hourly PE computed by the Campbell-Scientific CR-10X is downloaded in to an Excel spreadsheet to compute monthly averages. Results are presented in Table 1.

Table 1. Mean Monthly Evaporation Rates

Month	Mean Monthly Evaporation Rate (inches per hour)	Standard Error of Mean
JUL 2002	0.0113	0.00081
AUG 2002	0.0099	0.00060
SEP 2002	0.0062	0.00059
OCT 2002	0.0042	0.00049
NOV 2002	0.0022	0.00017
DEC 2002	0.0014	0.00014
JAN 2003	0.0016	0.00021
FEB 2003	0.0023	0.00032
MAR 2003	0.0044	0.00054
APR 2003	0.0073	0.00059
MAY 2003	0.0090	0.00080
JUN 2003	0.0114	0.00023

4. Soil hydraulic properties for the tailings surface are estimated with empirical equations suggested by Rawls and Brakensiek (1989) from grain-size data obtained from laboratory test results of near surface samples taken by SRK (2000). Grain-size information is provided in Table 2.

Table 2. Grain-Size Data to Estimate Soil Hydraulic Properties

Boring # and depth	Percent sand	Percent silt	Percent clay
AR5 @ 0'-1'	10	75	15
AR3 @ 6'-10'	12	74	14
AR9@ 2.5'-5.5'	87	10	3
AR2 @ 5.5'-10'	15	66	19
average	*31*	*56*	*13*
standard error	*16*	*13*	*3*

Using the average values from the grain-size analyses with equations presented by Rawls and Brakensiek (1989) produce a *Ksat* value of 0.53 cm hr^{-1} (1.5 × 10^{-4} cm sec^{-1}). Grain-size average results classify as a silt loam under the USDA classification system, and as a silt under the USCS classification system assuming low plasticity material. This estimate is within the range of published data by Lambe and Whitman (1969) for permeability of natural soils (pg. 286).

5. To determine the period of time during a day that will be used for Stage 1 evaporation it is specified for purpose of this calculation, as the time when hourly evaporation exceeds the monthly evaporation. This is illustrated in Figure 1. Monthly data was reviewed and the time for Stage 1 evaporation for individual months was specified and is provided in Table 3.

Table 3. Stage Allowed for Stage 1 Evaporation

Month	Time Allowed for Stage 1 Evaporation (hours)
JUL 2002	10
AUG 2002	9
SEP 2002	8.5
OCT 2002	8.5
NOV 2002	7
DEC 2002	7
JAN 2003	7
FEB 2003	7
MAR 2003	8.5
APR 2003	8.5
MAY 2003	9
JUN 2003	10

6. Total daily evaporation per month is computed as product of PE and Te as computed in Table 4. Total daily evaporation has units of length (inches) and is specified to be the cumulative infiltration (I) in the Green-Ampt one-dimensional infiltration.
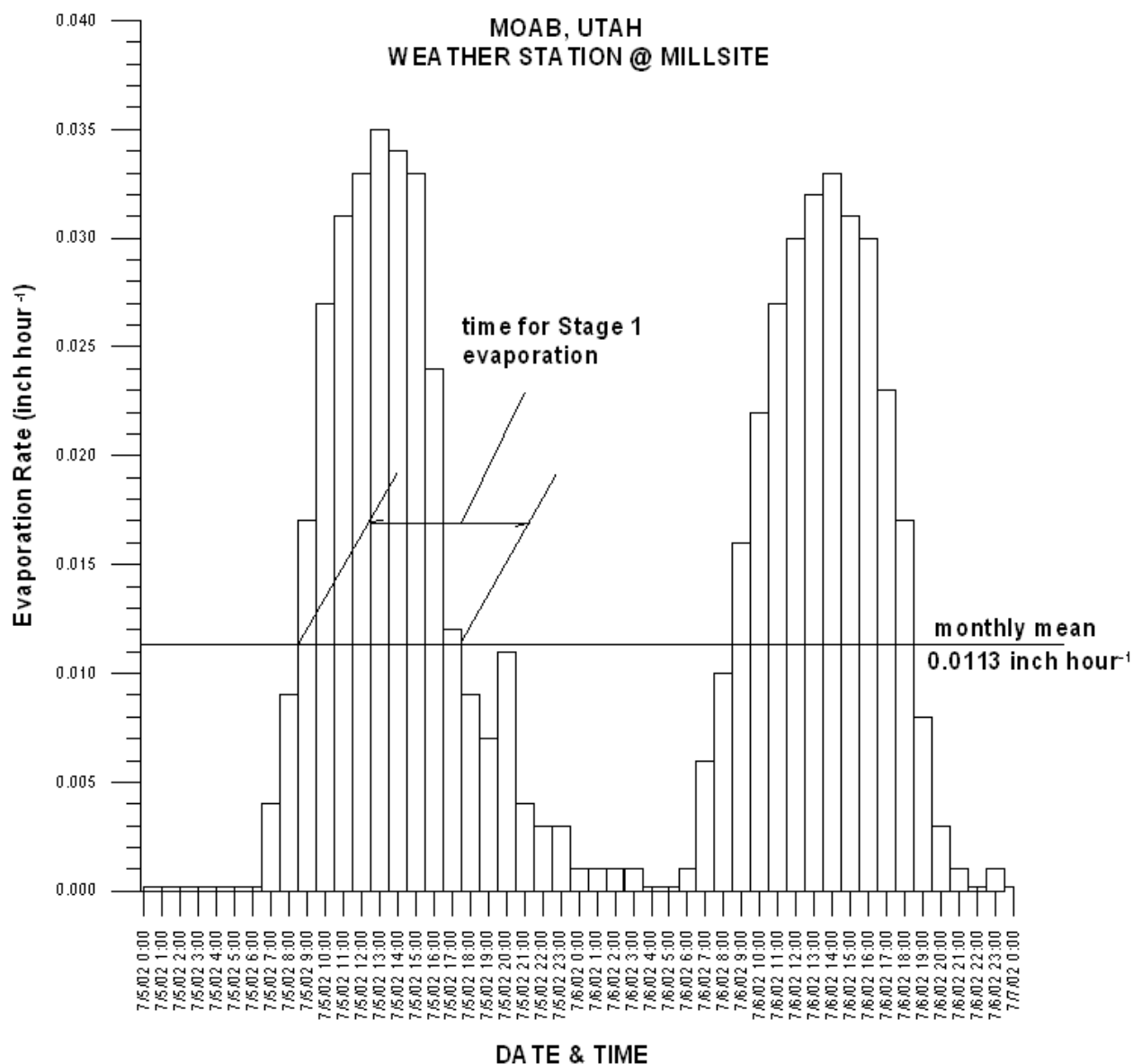
Figure 1

7. Cumulative infiltration is computed in Table 4.

8. Cumulative infiltration in Green-Ampt is equivalent to the product of a uniform application rate and time of application, or:

$$I = t * r$$

Therefore the time of application for water and to not allow percolation, nor surface saturation, nor runoff is computed as:

$$t = I/r$$

Table 4. Cumulative Evaporation Depth (inch)

Month	Mean Monthly Evaporation Rate (in/hr)	Time for Stage 1 Evaporation (hours)	Total Daily Evaporation = Cumulative Infiltration (inch)
JUL 2002	0.0113	10	0.1130
AUG 2002	0.0099	9	0.0891
SEP 2002	0.0062	8.5	0.0527
OCT 2002	0.0042	8.5	0.0357
NOV 2002	0.0022	7	0.0154
DEC 2002	0.0014	7	0.0098
JAN 2003	0.0016	7	0.0112
FEB 2003	0.0023	7	0.0161
MAR 2003	0.0044	8.5	0.0374
APR 2003	0.0073	8.5	0.0621
MAY 2003	0.0090	9	0.0810
JUN 2003	0.0114	10	0.1140

Application rates must be less than the saturated hydraulic conductivity of 0.53 cm hr^{-1} (0.21 inch hr^{-1}). A series of application rates ranging from 0.07 inch hr^{-1} to 0.5 inch hr^{-1} are computed and plotted on Figure 2.
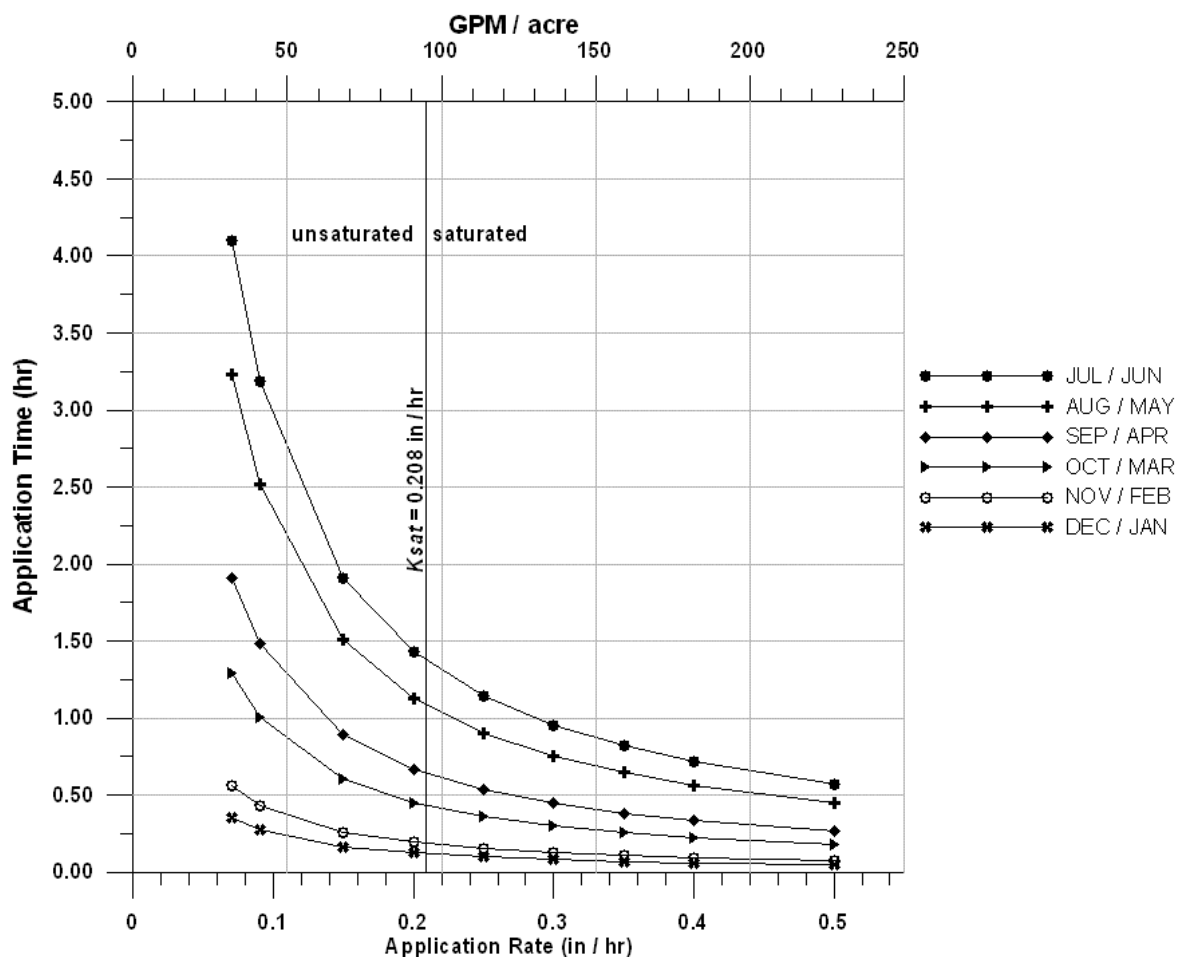

Figure 2

Discussion

An initial estimate of an allowable application rate of water on a bare soil surface with a time for complete evaporation of the applied water is computed herein. Ponding applied water or allowing applied water to runoff the area shall not be allowed. The computation assumes that the application rate is equal to the average monthly evaporation rate. Percolation into the soil could occur when the application rate exceeds the evaporation rate, which will occur 50% of the time on average. This is why water should not be applied during the high evaporation portions of the day, i.e. sunny times with higher temperatures.

The entire computation assumes a constant climate as defined by the climatic variables that occurred July 2002 to June 2003 at the Moab Project site, which will not be true. Thus, given the level of uncertainty in this computation, it is recommended that after installation and construction of a system that applies water at rates and for times intervals computed herein, the application rates be adjusted to fit actual site conditions. This will allow for maximum application during times when evaporation rates are less than average, i.e. early morning hours; and drying during times when the evaporation rate is greater than the average, i.e. the sunny time of the day.

Conclusion and Recommendations

Based on results shown in Figure 2, water can be applied to the surface of the tailings impoundment at Moab without causing percolation. For design purposes it is recommended that initial application rates between 50 gpm/acre and 80 gpm/acre. This results in application times ranging from approximately 2.75 hours to 1.75 hours during the height of annual evaporation (JUL / JUN) to 1.25 hours to 0.50 hours during the spring/fall (OCT / MAR). Application during winter months does not appear to be practical.